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# ECOLOGICAL FORECASTING

## NASA Earth Science
## Applied Sciences Program

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# *Applied Sciences Program*

## Ecological Forecasting: 2015 Annual Summary

*May 2016*

*Discovering and Demonstrating*
*Innovative and Practical Applications*
*of Earth Observations*

## *Ecological Forecasting: 2015 Annual Summary*

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## I. Introduction

The ESD Applied Sciences Program promotes efforts to discover and demonstrate innovative and practical uses of Earth observations. The Program funds applied science projects to enable near-term uses of Earth observations, formulate new applications, integrate Earth observations and related products in practitioners' decision making, and transfer the applications to long-term users. The projects are carried out in partnership with public- and private-sector organizations to achieve sustained use and benefits from the Earth observations.

The Applied Sciences Program's applications themes are currently focused on four of the eight Societal Benefit Areas (SBAs) of the international Group on Earth Observations (GEO) partnership: Health (including Air Quality), Disasters, Ecological Forecasting, and Water Resources.[1] The Program includes climate-related influences and impacts within each of these themes.

The Ecological Forecasting applications area combines satellite observations and many types of models to build capacity for forecasting changes in living systems. Natural resource managers, working on land and in the oceans, are a primary user community along with all those involved in the conservation and sustainable use of ecosystems in the United States and abroad.

## II. Overview of 2015

Ecological Forecasting continued to manage an active portfolio of projects in 2015. Ten feasibility projects went from the feasibility phase into the full implementation phase. The remaining DECISIONS 2008 project and a Climate and Biological Response (BioClim) project completed their activities. A solicitation released in early 2016 should result in new growth for the portfolio. The applications area continued its support of mission applications. Ecological Forecasting also participated in U.S. and international initiatives involving conservation and protected area management.

[1] The eight GEO SBAs are Biodiversity and Ecosystem Sustainability, Disaster Resilience, Energy and Mineral Resources Management, Food Security and Sustainable Agriculture, Infrastructure and Transportation Management, Public Health Surveillance, Sustainable Urban Development, and Water Resources Management.

This report presents some of the achievements, challenges, and activities for the Ecological Forecasting applications area over the past year. It also includes a brief outlook for 2016. The appendix includes individual project summaries with 2015 accomplishments and, as applicable, plans for the coming year.

## III. Major Accomplishments

Funding went out for 10 projects, down selected by means of a January review panel, to proceed from one year of feasibility activities to full project implementation under the Ecological Forecasting for Conservation and Natural Resource Management solicitation. These projects have three more years to bring together satellite remote sensing, ecological models and other types of models, and biological observations to promote conservation and sustainable ecosystem management. At least some of the required biological observations for each project originate from crowdsourcing initiatives, breaking new ground programmatically. A goal for crowdsourcing is to increase the number of *in situ* observations (currently a limiting factor in modeling changes to ecosystems and necessary to make forecasts). Drafted in 2015, the Ecological Forecasting A.46 solicitation seeks proposals addressing four topics: (1) large land/seascape connectivity; (2) the potential to use remote sensing to bring together energy companies and agribusinesses with conservation organizations to mitigate the impacts of farming and energy development on natural systems; (3) managing marine ecosystems in a time of changing climate through better forecasts; and (4) workshop proposals on using Earth observations to value ecosystem services. The last topic addresses a major new effort in the NASA Earth Science Division to build partnerships with private companies and nongovernmental organizations. One of the new partnerships getting underway in 2015 is with Conservation International (CI). Its focus is on developing remote sensing approaches for assembling ecosystems accounts and remote sensing-based indicators for CI's Freshwater Health Index. The applications area will review A.46 proposals and make selections in 2016.

On behalf of end user Monica DeAngelis at the NOAA Southwest Regional Office, Helen Bailey (University of Maryland Center for Environmental Science) led the WhaleWatch BioClim project that concluded in 2015. A model-based tool was developed using satellite telemetry and remotely sensed environmental data to provide near real-time predictions of whale occurrence in the California Current System to reduce whale ship strikes and entanglements with fishing nets. Model

development took advantage of a wide array of remotely sensed data: MODIS, *Topex/Poseidon*, *Jason* and other satellite measures providing sea surface height, sea surface temperature, chlorophyll-a, and net primary production. The new tool predicts the likelihood of Blue Whale occurrence on a seasonal basis and is updated on a monthly timestep. The NOAA Fisheries West Coast Region website is housing the tool (www.westcoast.fisheries.noaa.gov/whalewatch), and to promote sustainability an automated framework has been developed using freely-available software that does not require technical expertise from the end user. This will enable NOAA to access remotely sensed data inputs and update model outputs on a regular basis for access by shipping companies and fishermen for use in avoiding unwanted encounters with whales. A video overview of the project, "A Voice for Whales: Using Satellite Data to Protect Marine Mammals," is available at http://appliedsciences.nasa.gov/programs/ecological-forecasting-program#.

**IV. Assessment**

The overarching challenge for the NASA Applied Sciences Program is to support projects that develop products of value to the external community, i.e., our partners. The ultimate test of this value is the transfer of the NASA-funded products to sustainable use by partners in the partners' operational management and decision support frameworks. Transferring a NASA-funded product (the outcome of a NASA Applied Sciences project) into long-term use by a partner is very challenging and involves close coordination among NASA, the NASA-funded investigator, and the end-user partner from the inception of the project. The Ecological Forecasting associates have become quite proficient over the past years in monitoring and guiding individual projects throughout their life cycles—so necessary to promote successful transfers. The associates are a major asset to this applications area. Biweekly conference calls continue to prove useful in keeping all program management personnel on the same page.

The mission applications representatives are also strong contributors to the applications area—indeed, the entire Applied Sciences Program. They support the integration of applications into the development cycles of missions for which the Ecological Forecasting program manager serves as applications lead. Over the past year, they have spread the word about the applications potential of the *ICESat-2*, *PACE*, ECOSTRESS, and *HyspIRI* missions through applications traceability matrices, mission applications whitepapers, special sessions at meetings,

workshops, membership on mission science teams, development and implementation of Early Adopter programs, etc. Each of these four missions supports elements of Ecological Forecasting. The mission applications representatives continue to target communities with an interest in designing Ecological Forecasting projects to prepare for products from new missions. Monthly calls link applications area program management to mission applications reps. These representatives are instrumental in bringing applications into mission life cycles as early as possible.

## V. Project Portfolio

In 2015, the Ecological Forecasting applications area continued its transition from a series of productive and long-running DECISIONS and BioClim projects to implementation of the Ecological Forecasting for Conservation and Natural Resource Management projects. As the remaining BioClim projects conclude over the course of 2016, the Ecological Forecasting A.46 solicitation should rejuvenate the portfolio with a new round of projects.

## VI. Program Management

Investigators from the Ecological Forecasting applications area met at a special meeting of the entire NASA Carbon Cycle and Ecosystems Focus Area in April. This focus area joint science workshop brought together approximately 500 NASA investigators to discuss where focus area programs are headed and allowed these investigators to build relationships across a range of disciplines. These meetings are a significant opportunity for NASA program managers to learn what is working within the broader community and where we need to make improvements.

The *Hyperspectral Infrared Imager* (*HyspIRI*) is a mission concept called for in the 2007 NRC Earth Science Decadal Survey. This mission would combine a visible through shortwave infrared imaging spectrometer with a multispectral thermal infrared sensor—a powerful instrument combination for ecosystem understanding. Two *HyspIRI* events in 2015 addressed the needs of the communities in the NASA Applied Sciences Program. In June, NASA GSFC hosted its annual *HyspIRI* Data Products Symposium. This year's symposium addressed the future *HyspIRI* data products; their processing, calibration, and validation; and plans for the new National Research Council Decadal Survey for Earth Science and Applications. In addition, there was an aquatic forum on the third day of the symposium.

The annual *HyspIRI* Science and Applications Workshop took place in Pasadena, California in October. Talks included a wide range of applied topics: public health, water quality, dealing with fires and volcanoes, and atmospheric phenomena. There was also a session on the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) activity. ECOSTRESS is a relatively new mission selected in 2014 through the Earth Venture–Instrument solicitation. It will fly a multispectral thermal instrument aboard the International Space Station in 2018 and is leveraging much technology maturation work done for the *HyspIRI* thermal infrared sensor. One of three key science questions for ECOSTRESS is an applications question: Can agricultural vulnerability be reduced through advanced monitoring of agricultural water consumptive use and improved drought estimation? In addition to this session, ECOSTRESS held a science team meeting in November. Given its agricultural focus, USDA science team member Martha Anderson participated in this meeting.

The first *PACE* science team meeting took place in January 2015 in College Park, MD. Participants included CUNY/Maria Tzortziou and NASA LARC/Ali Omar, Applied Sciences *PACE* science team members. ICESat-2 hosted an Applications Workshop in March, which looked at the Vegetation and Glaciology, Hydrology, and Sea Ice and Open Ocean applications of the mission through breakout groups. In addition, there was an *ICESat-2* Inland Water Focus Session in November at the American Water Resources Association Annual Water Resources Conference.

**VII. Community Leadership**

In October, BioClim investigator Mitch Roffer led a Climate Variability and Fisheries workshop in St. Petersburg, Florida, that brought together state and Federal fisheries managers from throughout the Southeastern U.S. and NOAA Headquarters. The workshop leveraged the climate forecasting elements of the Roffer project to engage managers in wide-ranging discussions of how to prepare fisheries for climate change—influencing one of the topics in the current Ecological Forecasting A.46 solicitation.

Publications arising from the applications area in 2015 include Associate Maury Estes' work as a primary author on a chapter entitled: "Molts Reveal Life-History Patterns for Juvenile American Horseshoe Crabs in Fringe Habitats," in Changing Global Perspectives on *Horseshoe Crab Biology, Conservation, and Management*.

This Springer publication elaborates on recent progress of scientific studies on horseshoe crabs and new issues related to their conservation.

In the spring, the NASA Applied Remote Sensing Training (ARSET) activity offered its first five-week webinar series on Introduction to Remote Sensing for Conservation. The webinar series focused on the tools and data portals available for conservation and biodiversity with specific sessions on habitat monitoring, animal movement, and near-real time monitoring. The series featured guest speakers previously funded by the NASA Ecological Forecasting and Biodiversity programs including Jeff Cavner (University of Kansas) demonstrating Lifemapper, Walter Jetz (Yale University) demonstrating Map of Life, and Karyn Tabor (Conservation International) demonstrating Firecast. The animal movement session also featured Movebank, the webtool for monitoring animal movement. A total of 293 participants from 61 different countries, 270 different organizations, and 27 states attended the webinars.

**VIII. International Activities**

The Ecological Forecasting application area's Gary Geller arrived in Geneva, Switzerland in February to begin a two-year detail within the GEO Secretariat. His focus is managing the Biodiversity and Ecosystem Sustainability SBA, with an emphasis on the Group on Earth Observations Biodiversity Observation Network (GEO BON). Gary has galvanized several GEO BON activities including the development of Essential Biodiversity Variables (EBVs) and tied the Secretariat more closely to GEO BON leadership in Leipzig, Germany.

In June, Ecological Forecasting investigator Heather Lynch was invited along with a select group of Antarctic experts to discuss how the Antarctic might meet the Aichi Biodiversity Targets agreed upon by the Parties to the Convention on Biological Diversity in its Strategic Plan for Biodiversity 2011-2020. Three days of meetings were held in Monaco, the result of which was a draft assessment, heretofore referred to as the Monaco Assessment, of how Antarctica is fairing with respect to these Aichi Targets. This assessment is currently in the final stages of preparation for submission for publication.

The U.S. Marine Biodiversity Observation Network (Marine BON)—an element of GEO BON continued its three demonstration projects. A Marine BON All Hands meeting was held in conjunction with the NASA Carbon Cycle and Ecosystems

Focus Area Joint Science Workshop in April. Updates were provided on the three demonstration projects focused on the Chukchi Sea, Santa Barbara Channel and Florida Keys/Monterey Bay National Marine Sanctuaries. For more information on Marine BON, please see its new website at http://www.marinebon.org/.

## IX. Looking Ahead

The year 2016 will be an active one for the applications area. The ten Ecological Forecasting for Conservation and Natural Resource Management projects are completing their first year of implementation bringing together crowdsourced biological observations, satellite remote sensing, and ecological models. They will help demonstrate the potential of citizen-provided data sets to provide urgently needed *in situ* information for generating ecological forecasts. GEO BON is proceeding full-speed ahead with additional support from the NASA Applied Sciences Program. The Ecological Forecasting A.46 solicitation is out for proposals that should result in nine to twenty new Ecological Forecasting projects before the end of the year. All in all, the applications area has a growing global reputation as a source of innovative remote sensing solutions for the conservation and the sustainable use of our natural world and its resources.

## X. Appendix

### Ecological Forecasting Project Highlights from 2015

**Project**: Merging Satellite and Numerical Model Data in the California Current to Create Forecasts of Harmful Algal Blooms

Principal investigator: Clarissa Anderson, University of California at Santa Cruz

Project year: 2

Year-end ARL: 6

Description: This project introduces a method for predicting the spatial distribution of harmful algal bloom (HAB) and toxin (domoic acid) loads in the coastal region of the California Current System using a unique blend of numerical models (ROMS), ecological forecast models (GLM HAB) of target phytoplankton taxon (*Pseudo-nitzschia*), and gap-filled satellite ocean color imagery (MODIS with DINEOF). We are leveraging the distributed databases established by the Central

and Northern California Ocean Observing System (CeNCOOS) for data management, interface with end-users, and communication with regional partners. We are developing a forecasting system and analysis tool in partnership with the NOAA National Ocean Service (NOS) and the National Weather Service (NWS) as a test bed for transitioning results to an operational center to complement existing regional HAB forecasting systems.

End users: NOAA National Ocean Service (NOS)

Data sources, models, technology: *Aqua*/MODIS, VIIRS, ROMS, HABMAP, Jellywatch and Marine Mammal Center crowdsourced data

Major accomplishments in CY 2015:

- Completed a demonstration (that includes validation) and have beta-tested the prototype application system in a simulated operational environment (CeNCOOS/MBARI).
- Continue to run automatic updates of the HAB nowcasts and forecasts on CeNCOOS web pages that are open to the public as well as disseminated to targeted end-users.
- Launched a feedback survey to the CeNCOOS community and made the forecasts public to a wide group of science and management end users.
- Quantified overall performance of the models using observational time series of both *Pseudo-nitzschia* abundance and domoic acid for 2014 (showed good coherence and model skill).
- Modified a popular citizen science website for beachcombers that would allow them to easily record observations of marine mammal strandings in order to verify offshore model results of toxic events with crowdsourced data.
- Obtained and analyzed historical marine mammal stranding data (2007-2014) with respect to HAB monitoring and model data to assess their coherence.
- Added accounts on the S4 system, a weather-predicting supercomputer at the NOAA cooperative institute SSEC at the University of Wisconsin and are putting scripts on the system and testing them out in the end user environment with expected finalization of this transition by summer 2016.

Plans or expectations for 2016:

- Continue to create Forecast & Analysis Tools for applying guidelines to validation and forecast analysis. In Year 3, the UCSC group will work with NCCOS to further establish the precise nature of the final forecast product and the most appropriate destination for dissemination, whether via CO-OPs product pages and/or Listserves, and/or NWS dissemination systems.
- Continue to transfer HAB forecast products to the CeNCOOS data portal for interactive displays and time series searches by end-users.

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**Project:** A Tool Using Satellite Telemetry and Remotely Sensed Environmental Data to Provide Near Real-time Predictions of Whale Occurrence in the California Current System to Reduce Anthropogenic Impacts

Principal investigator: Helen Bailey, University of Maryland Center for Environmental Science

Project year: 4 (final)

Year-end ARL: 8

Description: The project goal is to reduce whale ship strikes and entanglements by providing near real-time predictions of whale occurrence.

End users: NOAA NMFS Southwest Regional Office

Data sources, models, technology: SSH, SST, chlorophyll-a, net primary productivity (*Topex*/*Poseidon*, *Jason*, SeaWinds, MODIS, AMSR-E, SeaWiFS)

Major accomplishments in CY 2015:
- Completed Blue Whale near real-time predictive model/tool and transitioned to the NOAA Southwest Fisheries Office with an automated framework that will promote sustainable use post project.
- Seasonal predictions of Blue Whale occurrence are being housed on the NOAA Fisheries West Coast Region website.
- Monthly whale occurrence prediction updates are provided and prior predictions are archived for use by shipping companies, fishermen and other

end users to reduce the likelihood of whale ship strikes and entanglements in fishing nets or other hazards.
- Developed a thermal habitat multi-species model for four whale species (Blue, Humpback, Gray and Fin).
- Progress was made in enhancing NOAA's stratified density model for gray whales and foraging model for the Pacific Coast Feeding Group.
- The Humpback whale habitat model is under development to predict occurrence during month of December (peak month for Dungeness crab fishery) and August a peak for fishing gear entanglements.
- The project video, "A Voice for Whales: Using Satellite Data to Protect Marine Mammals" was produced and is available on the Program website.

Plans or expectations for 2016: Project is complete.

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**Project**: Forecasting Coastal Habitat Distributions through Fusion of Earth Observations, Process Models, and Citizen Science: A Climate Change Adaptation Tool for the NOAA National Estuarine Research Reserve System

Principal investigator: Kristin Byrd, USGS

Project year: 1 (feasibility) (final)

Year-end ARL: 4

Description: Estuarine managers need ecological forecasting tools to prepare for the potential impacts of future climate change. In partnership with the NOAA National Estuarine Research Reserve System (NERRS), we will integrate Earth science observations to *in situ* observations with a model of tidal marsh elevations to forecast spatially explicit coastal habitat response to sea level rise, a key NERRS concern. We will focus feasibility research on a brackish marsh, Rush Ranch, one of two sites in the San Francisco Bay NERR.

End users: NOAA NERRS

Data sources, models, technology: vegetation biomass: *Landsat 8* and World View-2. Total suspended sediment: *Landsat 8*, PRISM, and World View-2

Major accomplishments in CY 2015:

- Mapped aboveground plant biomass for tidal marshes in Suisun Bay and mapped SSC in tidal channels and open water of Suisun Bay.
- Incorporated Earth observations of suspended sediment concentration (SSC) and aboveground peak biomass into the Marsh Equilibrium Model (MEM).
- Compared Landsat 8, World View-2 and hyperspectral PRISM sensors to determine the best data source for mapping biomass and SSC.
- Landsat 8 was found to be the most appropriate sensor for mapping SSC and biomass based on error analysis, cost and data access.
- Evaluated the use of the HydroColor iPhone App (measures water turbidity) as a citizen science activity to validate the SSC map. 21 kits were distributed and 16 returned for SSC comparisons and a $R^2$ of 0.71 was found between the app turbidity measurements and actual SSC.
- Evaluated a regional MEM based forecasting model for decision support; sensitivity analyses found that remotely sensed inputs are feasible for population at marsh sub-habitat model and that remotely sensed data may be better than field approaches for synoptically and repeatedly quantifying SSC.
- Active end user engagement continued with managers and scientists from the National Estuarine Research Reserves, NOAA Office of Ocean and Coastal Resource Management, and NOAA Coastal Services Center.

Plans or expectations for 2016: Project is complete.

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**Project**: Using NASA Resources to Inform Climate and Land Use Adaptation: Ecological Forecasting, Vulnerability Assessment, and Evaluation of Management Options across Two U.S. DOI Landscape Conservation Cooperatives (LCCs)

Principal investigator: Andrew Hansen, Montana State University

Project year: 4

Year-end ARL: 4

Description: The project is using TOPS models and products, Landsat imagery, and other data to demonstrate the steps of a climate adaptation strategy in two LCCs. The project intends to support decision making at national parks, LCCs, and similar organizations through the development of future climate and land use scenarios, ecological vulnerability assessments, and management adaptation strategies.

End users: Greater Yellowstone Whitebark Pine Subcommittee, Yellowstone National Park, Grand Teton National Park, Rocky Mountain National Park, Great Smoky Mountain National Park, Shenandoah National Park, Delaware Water Gap National Recreation Area, Great Northern LCC, Appalachian LCC, DOI North Central Climate Science Center, NPS Intermountain Region Climate Change Program

Data sources, models, technology: NASA multi-platform sensor data, NASA TOPS; *Landsat*

Major accomplishments in CY 2015

- Completed ecological hindcasting and forecasting of climate, ecosystem process, and tree species and communities under climate change scenarios.
- Used the hindcasts and forecasts as a basis for assessing vulnerability of land facets, tree species, and vegetation communities under land use and climate change.
- Projected climate to 2100 was downscaled and the climate projections are intended for resource management.
- Results on climate for the 1900-2100 period were summarized for national parks.

Plans or expectations for 2016:

- Publish additional scientific papers.
- Demonstrate climate adaptation planning for whitebark pine in the Rocky Mountains and for eastern hemlock in the Appalachians.
- Conduct final vegetation management workshops with stakeholders in the Rockies and in the Appalachians.

- Continue transferring decision support products to the Great Northern LCC, the North Central Climate Science Center, and the NPS I&M program.

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**Project**: The Effects of Extreme Climate Events on Avian Demographics: The Role of Habitat Refugia in Mitigating Climate Change

Principal investigator: Patricia Heglund, U.S. Fish and Wildlife Service

Project year: 4

Year-end ARL: 5

Description: Using MODIS, *Landsat*, and other data, this project seeks to predict the effects of extreme climate and weather events on bird demographics, as well as quantify the role of national wildlife refuges and national forests as refugia for waterfowl and forest birds, respectively. During extreme events, such as droughts and cold snaps, it hopes to identify management actions to enhance this refuge function.

End users: USFWS, USFS, the Nature Conservancy

Data sources, models, technology: MODIS, SRTM, AVHRR, AMSR-E, *Landsat*

Major accomplishments in CY 2015:

- Continued developed a draft web interface for downloading mapped weather data (19 variables) for North America for the period 1980-2013 (*http://silvis.forest.wisc.edu/data/BIOCLIM-Climate-Data-Access*).
- Projected changes in spring onset and false springs for the conterminous United States under two emissions scenarios until 2100.
- Analyzed velocity of shifting distribution patterns of 200+ bird species to illuminate current/predicted future location of weather refugia.
- Completed proof-of-concept that geographically extensive bird data collected once annually is able to characterize bird response to extreme weather detected at geographically local and intensively sampled sites.

- Determined over the study region, the median shift in spring onset was 23 days earlier in the Representative Concentration Pathway 8.5 scenario with particularly large shifts in the Western U.S. and the Great Plains.
- Concluded that global climate change may have complex and spatially variable effects on spring onset and false springs, making local predictions of change difficult.

Plans or expectations for 2016:

- Refine and expand the web interface for serving weather data—this will be accomplished with the help of additional of temporary staffing from GIS graduate students.
- Analyze waterfowl response to drought.
- Determine for passerine species the magnitude of movement versus productivity decline in response to extreme events.
- Analyze and develop maps of predicted future extreme event patterns for the United States from GCM output.

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**Project**: Snow, Montane Wildflowers, and Citizen Scientists

Principal investigator: Janneke Hille Ris Lambers, University of Washington

Project year: 1 (feasibility) (final)

Year-end ARL: 2

Description: This project combines MODIS-based images of snow covered area, citizen science observations, and models to generate spatially explicit seasonal forecasts of snow disappearance date and peak wildflower phenology to aid decision making by the National Park Service. The project team focused its one-year feasibility efforts in Mt. Rainier National Park, using downscaled MODIS-based fractional snow covered area to map snow disappearance, which can be used to predict the timing of peak wildflower season.

End users: National Park Service (NPS)

Data sources, models, technology: MODIS and MODSCAG

Major accomplishments in CY 2015:

- Manuscript accepted by *Park Science*, with two more in work, all together representing the physical, the biological, and the social aspects of the project.

Plans or expectations for 2016: Project is complete.

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**Project**: Avian Abundance Estimation across the Pacific Flyway for Full Life-Cycle Conservation Planning

Principal investigator: Steve Kelling, Cornell Lab of Ornithology

Project year: 2

Year-end ARL: 4

Description: The project goal is to provide a fully functional decision support tool for The Nature Conservancy of California to identify, at the field level (1 km x 1 km) weekly estimates of occurrence and abundance of all waterbirds (~50 species) that use the Western Flyway (from Alaska to Mexico). This support tool will be integrated into TNC's Bird Returns Reverse Auction program that leases agricultural fields (initially rice but will expand to other farming practices) to provide appropriate habitat for birds when birds are in the region and require habitat for feeding and roosting.

End users: The Nature Conservancy of California, land managers, climate forecasters, species distribution modelers

Data sources, models, technology: eBird citizen science data, MODIS and *Landsat* land products, species distribution models, etc.

Major accomplishments in CY 2015:

- The Nature Conservancy of California (TNC) has developed BirdReturns, a project that works with rice farmers in California's Central Valley to create flooded habitat for migrating waterbirds at the time and places when needed.
- A reverse auction process was again used to incentivize farmers to flood fields later in the spring migration and earlier in the fall to coincide with migration. In 2015, fourteen thousand acres of additional wetlands were made available.
- Continued development of a decision support tool (DST), initially for BirdReturns but adaptable to other projects.

Plans or expectations for 2016:

- The DST will provide precise knowledge of the temporal and spatial variation in bird abundance using eBird data.
- The DST will provide estimates of distributions and relative abundances of focal bird species to partners as GIS data layers that will be accompanied by spatially explicit information about the robustness of these estimates, all of which can be used interactively by end users to explore different management scenarios.

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**Project**: EcoCast: Improving Ecological and Economic Sustainability of Marine Fisheries Using Remotely Sensed Oceanographic Data

Principal investigator: Rebecca Lewison, San Diego State University

Project year: 2

Year-end ARL: 4

Description: The goal is to demonstrate the applicability of EcoCast, a near real-time, multi-species fisheries decision support tool. The project's objective is to develop a flexible and responsive application that will enhance conservation of protected and non-target species, while maintaining sustainability and profitability of the fishery.

End users: NOAA NMFS and California drift gillnet fishery

Data sources, models, technology: SSH, Eddy kinetic energy, Ekman upwelling, SST, Chl-a, depth, slope, *Topex*/*Poseidon*, *Jason-1*, *Jason-2*, AVHRR, *Aqua*/MODIS, SeaWifs, SeaWinds/QuikSCAT

Major accomplishments in CY 2015:

- Through the project, improving the quality and the types of data that can be used in fisheries management. Developed an additional baseline metric based on this improved data quality. Tested, improved and validated models for swordfish catch in September-December 2009 using boosted regression trees.
- Successfully integrated biological data (telemetry, fisheries observer data) with NASA satellite derived oceanographic data in a robust quantitative framework. Demonstrated for three species of interest in our focal fishery (leatherback sea turtle, sea lion, blue shark) the strength of the analytical approach and generated predictive models for this suite of species.
- Participation by members of the research team in a NASA-sponsored workshop and contributed to a book (Springer) and special issue (Review of Geophysics, AGU) on "Earth Science Satellite Applications: Current and Future Prospects" in support of the National Research Council (NRC) Decadal Survey. Additional funds were awarded by California Sea Grant (PI: Maxwell) to incorporate NOAA marine mammal sightings data into the EcoCast predictive distribution framework.
- Convened two expert panel reviews of our model output with members of the Highly Migratory Species Management team and NOAA scientists.
- Presented our project progress to the Pacific Fisheries Management Council in November 2015.

Plans or expectations for 2016:

- Continue processing of remotely sensed oceanographic data.
    - Resolving differing spatial resolutions of these data.
    - Examining time lags for a number of oceanographic variables (chlorophyll-a, wind, sea surface temp.).
- Model integration of biological, fisheries and oceanographic data and fitting and testing multiple models (e.g., generalized additive mixed models and boosted regression trees).
    - including additional bathymetric data in our predictive models.
    - validating presence / absence and tracking data as input for models.

    - accounting for seasonal changes in animal behavior and distribution.
    - exploring ways to incorporate logbook data into our analyses.
- Continue soliciting feedback for end users and stakeholders on data layers.
- Integration of ROMS model.

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**Project**: Projecting Effects of Climate Change on River Habitats and Salmonid Fishes: Integrating Remote Sensing, Genomics, and Demography to Inform Conservation

Principal investigator: Gordon Luikart, University of Montana

Project year: 2

Year-end ARL: 4

Description: This project links remote-sensing mapping of freshwater habitats with genetic and demographic data, as well as spatially explicit hydrological and thermal model outputs to assess the vulnerability of salmonid populations in current and projected climate conditions. Incorporating these new measures of habitat quality will enhance an existing decision support tool, the Riverscape Analysis Project.

End users: USGS, NOAA, U.S. Fish and Wildlife Service, Columbia River Inter-Tribal Fisheries, Idaho Department of Fish and Game, Montana Fish Wildlife and Parks, Wild Fish Conservancy, Wild Salmon Center

Data sources, models, technology: AMSR-E fractional cover of water and free/thaw dynamics, MODIS NPP, *Landsat*

Major accomplishments in CY 2015:

- Hosted a workshop on riverscape conservation that included key partners from the Pacific Northwest Aquatic Monitoring Partnership, the Columbia River Inter-Tribal Fisheries, the Wild Fish Conservancy and USGS. Topics discussed included needs for new remote sensing products for improving riverscape management.

- Published one paper entitled “Genetic diversity is related to climatic variation and vulnerability in threatened Bull trout” in *Global Change Biology*.
- Developed a more user-friendly web-based DSS to integrate tools and remotely sensed habitat and climate data sets, along with genetic and demographic data sets, for salmonid conservation.
- Used volunteers to hook and line fish to collect genetic samples for rainbow trout and brook trout.

Plans or expectations for 2016:

- Prototype the Climate Change Vulnerability Assessment tool online along with offline packaged software resources such as landscape genetic tools.
- Conduct a joint workshop with the Pacific Northwest Aquatic Monitoring Partnership on current best practices and uses of Climate Change Vulnerability Assessments metrics in salmonid conservation.
- Conduct a Climate Change Vulnerability Assessment for Puget Sound steelhead assessment for NOAA
- Volunteers will be used to collect eDNA samples in Western Montana to start an aquatic invasive species database.

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**Project**: Bayesian Data-Model Synthesis for Biological Conservation and Management in Antarctica

Principal investigator: Heather Lynch, Stony Brook University

Project year: 2

Year-end ARL: 7

Description: This project is developing a browser-based decision support mapping and analysis tool that integrates multiple streams of remote sensing data with field counts and citizen survey reports to calculate the current distribution and abundance of the Adélie penguin. This species is a key indicator species used to assess the impacts of fishing and climate change on the Southern Ocean ecosystem.

End users: Oceanites, Inc., Southern Ocean Observing System, Antarctic Treaty System

Data sources, models, technology: *Landsat*

Major accomplishments in CY 2015:

- Successfully developed a penguin colony retrieval algorithm for Landsat imagery.
- Completed archival analysis of Landsat imagery (from 1984).
- Developed an occupancy and abundance model for Adélie penguins.
- Completed a beta version of an interactive, browser-based geospatial decision support application. Tested application with selected end users.
- Started a field season to collect spectral information on penguin guano (November and December 2015).

Plans or expectations for 2016:

- Scale developed penguin retrieval tools to three additional penguin species: the emperor, gentoo and chinstrap penguins.
- Develop a radiative transfer model to improve the physics of the penguin breeding areas retrieval algorithm.
- Complete a fully functional DSS interface.
- Estimate final parameters for Dynamic Bayesian Network model using all available chinstrap, gentoo and emperor penguin data.
- Incorporate eBird observations from a special eBird cruise with National Geographic (January 2016) into the DSS.
- Present results at the Scientific Committee for Antarctic Research Open Science Conference.

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**Project**: Using the USGS Resource for Advanced Modeling to Connect Climate Drivers to Biological Responses

Principal investigator: Jeff Morisette, U.S. Geological Survey

Project year: 4

Year-end ARL: 7

Description: The project is enhancing the decision support tools of the Resource for Advanced Modeling (RAM) facility at the USGS Fort Collins Science Center. The project team developed a package called the Software for Assisted Habitat Modeling (SAHM) within the open-source VisTrails scientific workflow tool.

End users: USGS RAM, field ecologists, land managers, climate forecasters, habitat modelers

Data sources, models, technology: MODIS and *Landsat* land products, gridded historical and projected climate data, etc.

Major accomplishments in CY 2015:

- Continued improvements on VisTrails:SAHM into RAM to enhance the tools available to field ecologists, land managers, climate forecasters, and habitat modelers.
- Supported programmers at the North Central Climate Science Center; expanded on the year 3 work of having VisTrails:SAHM software take advantage of multiple processors to explore supercomputers at USGS Denver, and Amazon cloud (with the objective of further reducing processing times from days to hours, yielding quicker model calculations that allow analysis of "what if" scenarios for various ecological questions and future climate projections).
- Institutionalized SAHM training at DOI every 6 months, see http://pubs.usgs.gov/fs/2014/3007/.
- Worked with NYU on SAHM:VisTrails module to display predictor response curves, to explore interactions between predictors and compare predictors across modeling techniques.

Plans or expectations for 2016:

- Finalize project tools for handoff to partners while continuing to improve technical aspects of SAHM.
- Develop strategy and workflow to utilize USGS Denver supercomputer.

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**Project**: System for Mapping and Predicting Species of Concern (SMAP-SOC)

Principal investigator: John Olson, Desert Research Institute

Project year: 2

Year-end ARL: 5

Description: This project combines Earth Observations of hydrology, vegetation, and surface thermal conditions with observations of species to develop a tool to map current and future distributions of freshwater species of concern by combining remote sensing data with environmental DNA in species distribution models. These maps can then be used by BLM to inform decisions on actions to either protect species or minimize invasive species.

End users: U.S. Bureau of Land Management (BLM)

Data sources, models, technology: MODIS, *Landsat*, empirical water chemistry models

Major accomplishments in CY 2015:

- Collected e-DNA samples from 64 sites across National Petroleum Reserve – Alaska (NPR-A, North Slope).
- Obtained tissue samples of 17 fish species from northern Alaska needed to test and develop e-DNA assays.
- Completed development of e-DNA assay for *Lota lota* and finalizing assays for *Esox lucius* and *Thymallus arcticus.* Initial assay of *Coregonus* species developed, but more refinement needed to separate species.
- Completed e-DNA assays for *Lota lota* on all 64 e-DNA samples, 25 presences detected.
- Obtained Earth observations for northern Alaska from ABoVE and other sources and have begun extracting data for all stream segments using new methods developed by USEPA.
- Established funding source from BLM to support project.

Plans or expectations for 2016:

- Continue to collect samples and develop genetic markers for six fish species (broad and humpback whitefish, Artic grayling, least cisco, burbot, and northern pike) found in Alaska.
- Assemble additional Earth observation data for evaluation as predictors, including SAR data indicating winter refugia for fish, snow cover (MODIS), and ground and soil water storage from *SMAP* and *GRACE*.
- Develop and test prototype interface for application.

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**Project**: Adaptive Ecosystem Climatology

Principal investigator: Bradley Penta, Naval Research Laboratory

Project year: 2

Year-end ARL: 5

Description: We will develop an Adaptive Ecosystem Climatology (AEC) to provide a flexible, online tool for ecoforecasting applications; it will meld observations collected by amateur observers (crowdsourcing), Earth-observing satellites, archived *in situ* data, and output from a state-of-the-art, data assimilative, coupled bio-optical-physical ocean model system. The AEC mitigates the shortcomings of the components and combines their strengths to enhance decision-making activities of our end-user, partner organizations (NOAA, BOEM, and EPA).

End users: NOAA, BOEM, EPA, Gulf of Mexico (GOM) Alliance, NOAA Southeast Fisheries Science Center, NOAA NCDDC, NOAA Atlantic Oceanographic and Meteorological Lab, Gulf States Marine Fisheries Comm., Mississippi River/GOM Watershed Nutrient Task Force

Data sources, models, technology: SeaWiFS, *Aqua*/MODIS, MERIS, and VIIRS. Products include SST, chlorophyll concentration, phytoplankton absorption coefficient, suspended particulate matter, diffuse attenuation coefficient, and euphotic depth

Major accomplishments in CY 2015:

- Compiled GOM EO (1997-2013) and model reanalysis runs from 1979-2013.
- Compilated the initial GOM ocean model climatology and historical in-situ data.
- Developed Coefficient of variation product for both chlorophyll and sea surface temperature.
- Developed Prototype GUI for web-based decision-support tool and web tool interface ('front end') prototype is complete.
- Developed Prototype OSKit (Education and Outreach component) and delivered kits to participating secondary school that students will use to gather citizen science data.
- Created OSkit mobile app Version 1 that will be used by students, volunteers and conservationists to gather crowdsourced data.
- Created Static GOM climatology products and evaluation/comparison of GOM AEC fields to standard climatologies was performed.
- Implemented tools for assimilation of historical in-situ data sets and built metadata database and query tools for in-situ data.
- Deployed AEC system on NOAA NCDDC computing facilities.
- Transferred AEC products to NOAA and BOEM end users for evaluation and use.
    - NOAA SEFSC is using AEC website (NOAA servers), data distribution, and product (static climatology) to drive OSMOSE (ecosystem) model.
- Two proposals have been selected and funded through the RESTORE Act to use AEC.
    - In collaboration with NOAA and university partners, AEC products are being prepared for use by three different types of fishery models: OSMOSE, ATLANTIS, and ECOPATH/ECOSIM/ECOSPACE.

Plans or expectations for 2016:

- Test methodology and refine as needed for assimilating crowdsource (PMN and OSKits) data.
- Test-Improvement Cycle (enhancements and bug fixes on demand).
- Rerunning long-term model with improvements and additional AEC output variables based on end-user input.
- Downloading and processing of US West coast Earth Observation products.

- Begin work on extension of AEC system to US East Coast.
- Pursue agreements with Apple, Google or other to provide OSkit app that can be used to expand the collection of crowdsourced data.
- Expand the community of end users with NOAA and other organizations as additional coastal products are developed for the Gulf and West coastal regions.

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**Project**: Monitoring and Forecasting Chimpanzee Habitat Health in Africa to Inform Conservation Actions and Strategies, and Measure Success

Principal investigator: Lilian Pintea, Jane Goodall Institute

Project year: 2

Year-end ARL: 3

Description: This project applies 30-meter resolution Landsat data with a habitat suitability model and a model forecasting future land use change, enhanced by crowd-sourced field data collected by local communities and protected area rangers using mobile smartphones and tablets, to annually monitor and forecast chimpanzee habitat health in Africa.

End users: Jane Goodall Institute

Data sources, models, technology: *Landsat*, MAXENT, Random Forests, DINAMICA EGO, Android smartphones and tablets, Open Data Kit (ODK) mobile data collection app.

Major accomplishments in CY 2015:

- Refined chimpanzee habitat suitability models, which predict distribution and estimate the current habitat health status of the chimpanzee in East and Central Africa at 30-meter resolution.
- Used forecasting model, which predicts future chimpanzee habitat health until 2030, taking into account business-as-usual scenarios of land cover and land use change that occurred between 2000 and 2012.

- Scaled-up community-based crowdsourced data collections in Africa using Android mobile devices and ODK app and demonstrated that crowdsourced efforts could be an important source of data for the development and validation of species distribution, land cover change and habitat health models.

Plans or expectations for 2016:

- Complete technical needs analysis for data and model integration (ARL 4).
- Integration of components into functioning DSS prototype hosted on a local server (ARL 5).

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**Project:** Management and Conservation of Atlantic Bluefin Tuna and Other Highly Migratory Fish in the Gulf of Mexico under IPCC Climate Change Scenarios: A Study Using Regional Climate and Habitat Models

Principal investigator: Mitchell A. Roffer, Roffer's Ocean Fishing Forecasting Service, Inc.

Project year: 5 (no-cost extension)

Year-end ARL: 9

Description: The project focuses on enhancing the management of multiple important highly migratory pelagic fish species in the Gulf of Mexico and surrounding waters, with particular focus on Atlantic bluefin tuna (*Thunnus thynnus*) and other highly migratory tunas and billfishes—in the Gulf of Mexico area for spawning and larvae and the north Atlantic Ocean including the Gulf of Mexico for adults. Applying Earth observations, the study projects a habitat model using IPCC climate change scenarios to assess possible effects of climate change on spawning habitat and fish population dynamics.

End users: NOAA NMFS SEFSC, University of Miami, and University of South Florida. Additional partners include the University of Southern Mississippi, University of South Carolina, NOAA NMFS offices, international partners in Mexico

(CONABIO) and Spain (Spanish Institute of Oceanography), and the International Commission for the Conservation of Atlantic Tunas (ICCAT).

Data sources, models, technology: MODIS and VIIRS (SST, ocean color), AVHRR (IR SST), Altimetry, SeaWifs, Metop a and b, CZCS and Meris

Major accomplishments in CY 2015:

- The results of the habitat classification are being used for the larval index by NMFS and in the stock assessments of other highly migratory adult species such as yellowfin tuna and swordfish, along with adult bluefin tuna.
- The use of satellite data in habitat classification modeling has been transferred to NOAA NMFS and is being sustainably used independent of project support.
    - As other personnel in NOAA NMFS are using the results of our research routinely and outside of our project, it appears that the operational use in decision making is being sustained.
- Provided daily satellite ocean oceanographic analyses to NOAA research vessel for an ichthyoplankton cruise in the South Atlantic, Caribbean and northern Gulf of Mexico.
    - Field research sampling schemes are using the habitat model derived from infrared and ocean color satellites to design the location of the field sampling, as well as, to adjust the sampling stations based on real-time satellite data.
- Climate modeling results indicate that the Yucatan Current and Caribbean current transport will be reduced during 21st century (under both RCP4.5 and RCP8.5 scenarios). This is associated with the slowing down of the Atlantic meridional overturning circulation (AMOC).
- In April, May, and June, there is minimal warming in northern GoM due to reduced Loop Current.
- Three refereed journal publications were completed:
    - Liu, Y., S.-K., Lee, D.B. Enfield, B.A. Muhling, J.T. Lamkin, F.E. Muller-Karger, and M.A. Roffer. 2015. Impact of global warming on the Intra-Americas Sea: part-1. A dynamic downscaling of the CMIP5 model projections. J. Mar. Syst. 148:56-69.
    - Hooidonk, R.V., J.A. Maynard, Y. Liu, and S.K. Lee. 2015. Downscaled projections of Caribbean coral bleaching than can inform conservation planning. Global Change Biol. Doi: 10.1111/gcb.12901.

- Muhling, B.A., Y. Liu, S.-K. Lee, J.T. Lamkin, M.A. Roffer, F.E Muller-Karger, and J.F. Walter III. 2015. Potential impact of climate change on the Intra-Americas Sea: Part-2. Implications for Atlantic bluefin tuna and skipjack tuna adult and larval habitats. J. Mar. Syst. 148: 1-13.

Plans or expectations for 2016:

- Provide real-time daily oceanographic analyses to the research vessel during the two-month SEAMAP research cruise in the spring.
- Provide post-cruise analyses after fish identifications returned.
- Finalize results of the bio-geochemical modeling to direct the thinking of NOAA NMFS Southeast Fisheries Science Center for future research planning. Provide forecasts of habitat expansion, contraction, or shifts for the next 100 years, at decadal intervals, for a range of CO2 emission scenarios derived from a refined downscaled biogeochemical model.
- Quantify changes in species distribution, species dominance, and levels of interaction between species across the Gulf of Mexico, through to the end of the 21st century.
- Complete training and transfer of tools, programs, and models to NOAA.
- Deliver final report.

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**Project**: Bringing Wildlife Management into Focus: Integrating Camera Traps, Remote Sensing and Citizen Science to Improve Population Modeling

Principal investigator: Phil Townsend, University of Wisconsin at Madison

Project year: 2

Year-end ARL: 6

Description: This project will link animal populations and remote sensing data derived from MODIS and Landsat imagery to model spatio-temporal patterns of animal occupancy statewide. Spatially explicit models of occupancy and abundance will be developed for specific animal populations including black bear, grey wolf, bobcat, and beaver, improving the population and management

models that the Wisconsin Department of Natural Resources currently uses for decision making.

End users: Wisconsin Department of Natural Resources (WDNR)

Data sources, models, technology: MODIS phenology, *Landsat*

Major accomplishments in CY 2015:

- Deployed and operated 500 cameras across the state of Wisconsin.
- Implemented a fully automated photo processing system from cameras to WDNR to Zooniverse
- Completed "soft rollout" of Snapshot Wisconsin crowdsourcing website through Zooniverse.
- Linked camera trap locational data to MODIS imagery, land cover, and climate observations.
- Developed animal occupancy models based on earlier 2010-2012 Central Wisconsin data.

Plans or expectations for 2015:

- Deploy 1000+ additional cameras throughout the state.
- Full public rollout of Snapshot Wisconsin crowdsourcing website.
- Continued development of animal occupancy modeling using 2014 and 2015 data generated by Snapshot Wisconsin.
- WDNR will begin to use the data and models for resource decision-making.

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**Project**: A Decision Support System for Monitoring, Reporting, and Forecasting the Ecological Conditions of the Appalachian National Scenic Trail

Principal investigator: Yeqiao Wang, University of Rhode Island

Project year: 6 (no-cost extension) (final)

Year-end ARL: 6

Description: The project team worked with the U.S. Park Service, Appalachian Trail Conservancy, USGS, and U.S. Forest Service to apply Earth observations, including MODIS data and TOPS models and data products, to an Appalachian Trail Decision Support System (DSS). The project team designed the DSS for monitoring, reporting, and forecasting ecological conditions. By integrating NASA EOS data and modeling products that link climate models and ecological models with in situ observations, the DSS provides critical information to improve effectiveness of decision-making in land management and for biodiversity conservation.

End users: foresters, land managers, park rangers, fish and game officials, natural resource managers, trail users

Data sources, models, technology: MODIS, TOPS and products, *Landsat*

The project concluded in August of 2015 with these major findings:

- The seamless time series data and modeling outputs provided specific information for understanding the dynamic and changing A.T. environment.
- The data and information revealed landscape scale patterns and change of environmental vital signs of phenology and climate change, forest health, and landscape dynamics.
- The developed prototype demonstrated that the geospatial data and modeling outputs can provide information for decision support exercises such as habitat suitability and risk analysis under drivers such as climate change.
- The Internet-based decision support interfaces and toolsets represent the state-of-the-art system for visualization, implementation and dissemination, developed to meet demands of geospatial data at landscape level for the A.T. corridor area.
- Data and information presented and packaged at different scales can provide information for decision support across different levels of management, as well as convey meaningful information to the American public.

Plans or expectations for 2016: Project is complete.

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**Project**: A System to Forecast the Demographic and Genetic Viability of Salmonid Fish across Broad Regions under Changing Climates

Principal investigator: Seth Wenger, University of Georgia

Project year: 2

Year-end ARL: 5

Description: Conservation management for salmonids (trout + salmon), as for other taxa, often requires decisions on the allocation of scarce resources. Ideally this conservation planning would be supported by population viability analyses (PVAs), but until now there has been a lack of accessible, data-driven methods for PVA that can be used across broad spatial scales. We have developed two new approaches to PVA: (1) ST-PVM, a statistical spatio-temporal demographic population viability model, and (2) CDMetaPOP, a flexible, individual-based model that can follow the genetic signature of 100s of thousands of simulated individuals, providing estimates of demographic and genetic viability. These new methods fill a crucial gap, connecting population ecology and genetic approaches that rely on extensive field collections with landscape ecology methods that rely on broad-scale Earth observations. The resulting estimates of population viability will be incorporated into decision support systems of various state, federal, and non-governmental organizations.

End users: Trout Unlimited, U.S. Forest Service, U.S. Fish and Wildlife Service, U.S. Geological Survey, Bureau of Land Management, Seattle City Light, and state agencies from Nevada, California, Utah and Montana (among others).

Data sources, models, technology: *Landsat* NDVI, *Landsat* NLCD, MODIS snow cover fraction, MODIS net primary productivity, NLDAS-2 and NASA Earth Exchange

Major accomplishments in CY 2015:

- Successfully tested modeling system using prototype data for Lahontan cutthroat trout. Evaluated candidate covariates derived from remotely sensed data to explain population dynamics.

- Results have been discussed with decision-makers in webinars and in-person meeting.
- Constructed a new model of stream temperatures for the Lahontan Basin, which are important model inputs.
- Developed all 3 sub-models and combined them for the final formulation of the ST-PVM model.
    - Observation model to account for observation error (imperfect detection of fish present during multi-pass electrofishing surveys).
    - Sampling model to scale up site-based estimates of fish abundance to estimate the entire population size, including unsampled sites.
    - Process model to describe changes in population sizes over time by estimating population growth rates and carrying capacities based on environmental covariates.
- Successfully ran the spatio-temporal PVM with 125 populations and the important growth rate predictors found were water temperature and high flow magnitude.
- Important predictors of carrying capacities were found to be: population extent, brook trout densities, high flow magnitude, and NDVI (riparian- and catchment-scale vegetation biomass).
- Two publications were accepted:
    - Dauwalter DC, Fesenmyer KA, Bjork R. Using aerial imagery to characterize redband trout habitat in a remote, desert landscape. Transactions of the American Fisheries Society. Accepted.
    - Scribner KT, Lowe WH, Landguth EL, Luikart G, Infante DM, Whelan GE, Muhlfeld CC. Applications of Genetic Data to Improve Management and Conservation of River Fishes and Their Habitats. Fisheries. Accepted.
- Continued to expand a comprehensive, versatile database of fish collection records to meet project modeling needs, for end users/stakeholders' additional uses, and as a repository for future collections.

Plans or expectations for 2016:

- Present current modeling results for Lahontan cutthroat trout to managers in March 2016.
- Crowdsourced data will continued to be collected and used from a large pool of federal and state agencies.
- Expand stream temperature modeling into California.

- Continue evaluating remotely sensed NDVI as a watershed covariate in the Population Viability Model.
- Work with end users to determine modeling management scenarios that are of the most interest and design modeling approaches to test.
- Exploring alternative approaches for incorporating brook trout data as a predictor of Lahontan cutthroat trout carrying capacities. These scenarios will include the following.
    - Estimate viability of LCT under climate change scenarios.
    - Fish Reintroduction scenarios.
- Continue to refine and evaluate the dessication model.
- Continue to improve our modeling platforms to cover multi-species modeling and species interactions (e.g. Brook Trout, Southwestern Trout, Redband Trout, Yellowstone/Westslope and Bonneville Cutthroat).
- Begin to design user interface development requirements to promote effective transfer and sustainability of model/tool products post project.
- Continue expanding the fish database.

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**NASA Applied Sciences Program**
**Ecological Forecasting Applications Area**

**Program Manager**
Woody Turner
*woody.turner@nasa.gov*

**Associate Program Managers**
Maury Estes
*maurice.g.estes@nasa.gov*

Cindy Schmidt
*cynthia.l.schmidt@nasa.gov*

Jay Skiles
*joseph.skiles@nasa.gov*